Aug. 4, 1953 A. H. DICKINSON 2,647,995

TRIGGER CIRCUIT

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FIG. 1

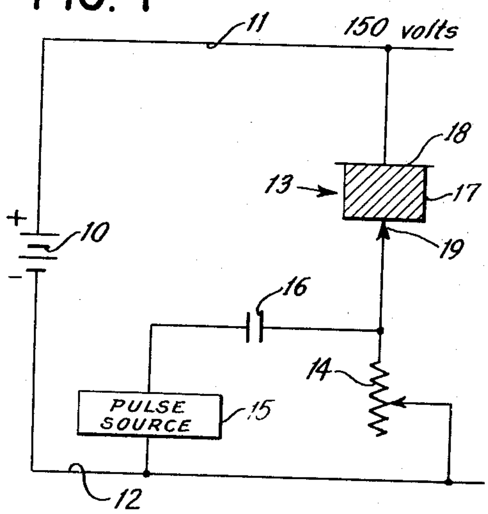


FIG. 3

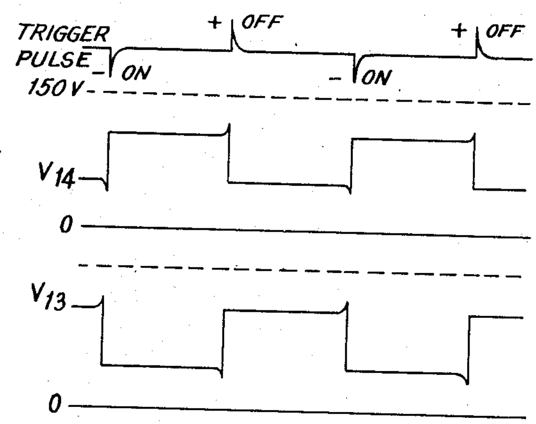


FIG. 4

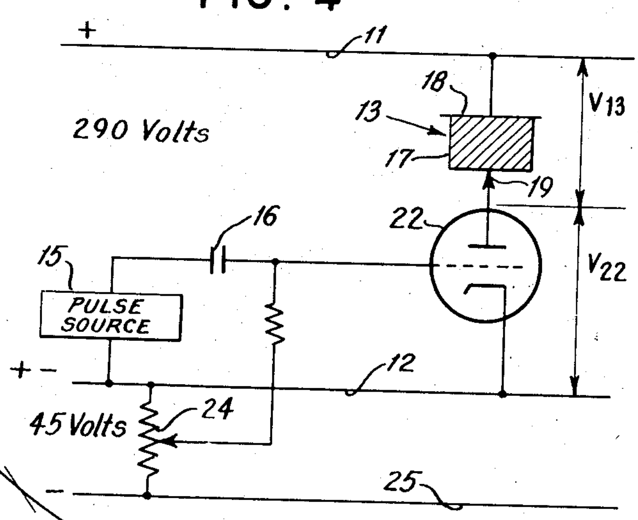


FIG. 2

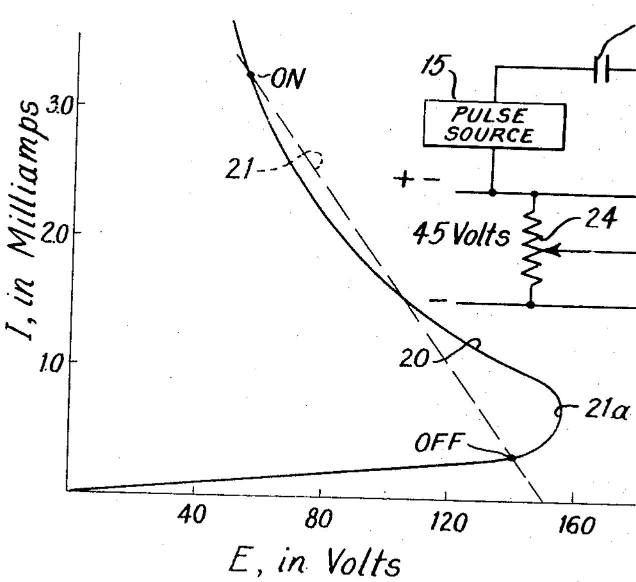


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FIG. 6

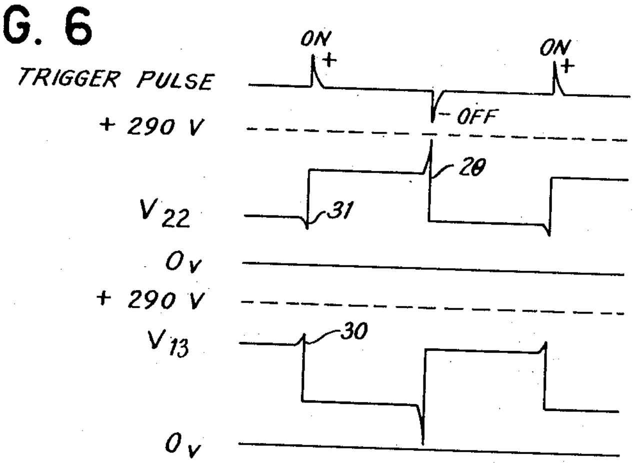



FIG. 7

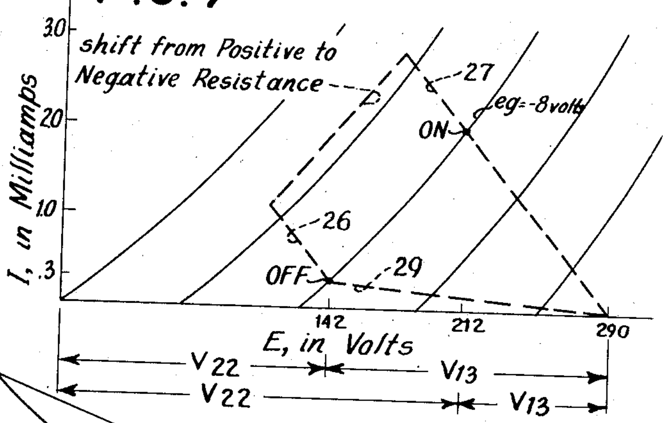
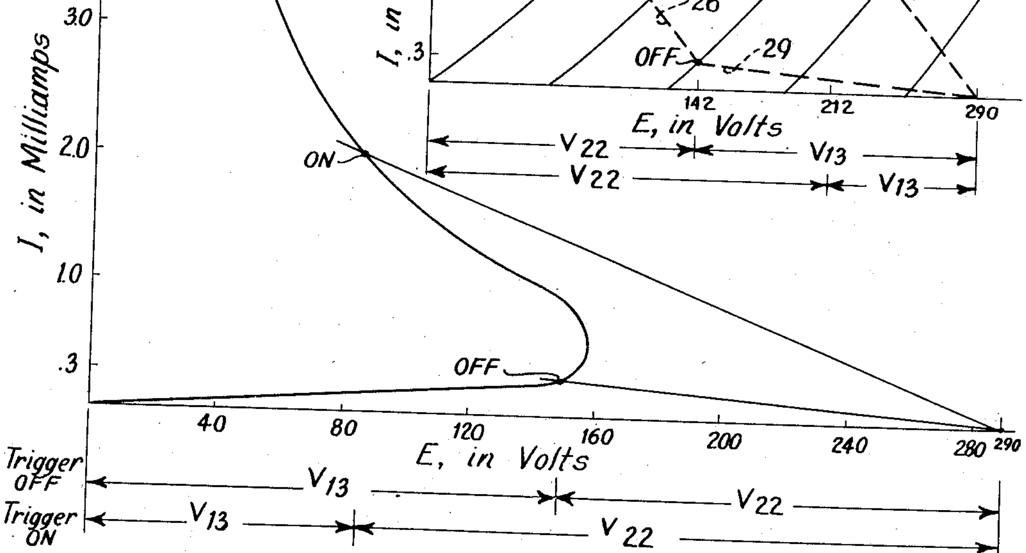



FIG. 5

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Patented Aug. 4, 1953

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# UNITED STATES PATENT OFFICE

2,647,995

## TRIGGER CIRCUIT

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Application December 7, 1950, Serial No. 199,687

6 Claims. (Cl. 250—27)

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This invention pertains in general to a trigger circuit and more specifically to a trigger circuit in which the usual electron tubes are replaced by a crystal diode.

A crystal diode, so-called due to the analogy of the functioning thereof to the motion of electrons in a vacuum-tube diode, may be briefly described as a rectifying element including a minute block of "doped" semi-conductor having a positive and negative resistance characteristic under certain operating conditions, such as germanium or silicon, which is plated with metal on one surface and connected with an extremely fine metallic whisker on the parallel surface. The positive resistance characteristic may be defined as one in which there is a change in current in the same sense for each change of potential while in the case of the negative resistance characteristic the current varies inversely with the voltage. A trigger circuit including the crystal diode may be formed with a current limiting element being placed in series with the metallic whisker with a suitable pulsing source for effecting the triggering action.

The principal object of the invention is to provide a trigger circuit in which the so-called triggering action is brought about by an induced change in the resistance characteristics of a crystal diode.

A further object of the invention is to provide a trigger circuit in which the status thereof is altered by the initiation of a change in the resistance characteristic of a crystal rectifier rather than by an initiation of a change in the potential of a control grid or plate of a vacuum tube.

Another object of the invention is to provide a trigger circuit in which the trigger action is brought about due to a change in the physical and electrical characteristics of a block of semi-conductor material.

A still further object of the invention is to provide a trigger circuit including an element of semi-conductor material having two conditions of stable equilibrium.

A still further object of the invention is to provide a trigger circuit including a block of semi-conductor material regeneratively operable in its transversal from either of two states of stable equilibrium to the other.

This invention will best be understood by reference to the accompanying drawing, in which:

Fig. 1 is a circuit diagram of the main embodiment of the invention and showing the arrangement of the crystal diode in the circuit.

Fig. 2 is a characteristic curve for the crystal diode and showing the positive and negative resistivity features of the crystal diode.

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Fig. 3 is a diagram showing the characteristic waveforms of the circuit of Fig. 1 while in operation.

Fig. 4 is a modification of the invention in which a vacuum tube is serially connected with the crystal diode in place of the resistor of Fig. 1.

Fig. 5 is a dynamic characteristic curve of the circuit of Fig. 4.

Fig. 6 is a diagram showing the characteristic waveforms of the circuit of Fig. 4 during an operating condition.

Fig. 7 represents the operation of the trigger with reference to the usual plate current plate voltage characteristics of the vacuum tube of Fig. 4.

Referring now in detail to Fig. 1, there is shown therein a source of operating potential 10 of the magnitude of approximately 150 volts and supplying energy to the novel trigger circuit through the positive conductor 11 and the negative conductor 12. There is coupled between the conductors 11 and 12 the novel trigger circuit including the crystal diode 13 and the current limiting resistor 14. A source 15 of positive and negative pulses is coupled through the capacitor 16 to the junction of the diode 13 and the resistor 14. An output voltage for control purposes may be taken from the junction of the diode 13 and the resistor 14 and the line 12.

The crystal diode 13 includes a minute block of "doped" semi-conductor 17, such as germanium or silicon, which is plated with a metallic base 18 on one surface and connected with an extremely fine metallic whisker 19 on the parallel surface. Now when the applied voltage of the base 18 with respect to the whisker 19 is positive, as is the case of Fig. 1, the diode exhibits relatively high resistance properties commonly termed high back resistance. Also when the applied voltage of the whisker 19 with respect to the base 18 is positive the diode exhibits relatively low resistance properties commonly referred to as low forward resistance. Thus the crystal diode 13 having the features of a high back resistance and a low forward resistance, which are essential characteristics of a rectifier, functions as a rectifying element. As described in "Crystal Rectifiers" by H. C. Torrey and C. A. Whitmer, Radiation Laboratory Series vol. 15 (McGraw-Hill 1948), the rectifying action of the crystal diode results from the properties of the surface layer of the semi-conductor 17 at the point contact with the whisker 19. In the region of this contact, there is an excess concentration of negative charge which acts as a potential barrier to the flow of electrons from the semi-conductor or crystal into the whisker. When a negative potential is applied to the whisker, the height of this barrier is increased so that the number of electrons having sufficient energy to pass over the barrier is greatly diminished. But when a positive potential is applied to the whisker, the number of electrons having sufficient energy to pass over the barrier is increased. If the relation between the current passed by the barrier and the voltage applied between the whisker and the base were linear, there would be no rectification since the resistance would be constant. However, this is not the case since this relation is exponential and therefore extremely non-linear thereby making rectification possible by approximating the characteristic curve of an ideal rectifier. A more complete description concerning the barrier theory of rectification may be found in the aforementioned textbook.

The functioning of the trigger circuit of Fig. 1 depends upon the feature of the crystal diode characteristic curve **20** (Fig. 2) of the existence of a negative-resistance region after the attainment of a maximum voltage as denoted by reference character **21**$a$. The characteristic curve **20** of Fig. 2 which represents the locus of operating conditions to which the diode reverts is obtainable by static voltage and current measurements.

The insertion of the resistor **14** in series with the diode **13** results in a circuit which, as shown by the plurality of intersections of the load line **21** with the characteristic curve **20**, may be switched from the "off" stable position to the "on" stable position, or vice versa, by the application of a suitable potential thereto from the pulse source **15**. It is to be noted that the characteristic curve obtainable for different germanium or silicon crystal diodes varies with each crystal and also that the slope of the load line **21** is dependent upon the magnitude of the resistor **14**.

When the trigger is in an off position, as shown in Fig. 2, the voltage drop across the crystal diode **13** is larger than the voltage drop across the resistor **14**, as shown by the respective waveforms $V_{13}$ and $V_{14}$ in Fig. 3. When a negative pulse from the source **15** is applied to the junction of the resistor **14** and the diode **13**, the voltage drop across the diode **13** increases until it reaches the maximum voltage **21**$a$ (Fig. 2) at which time there is a change in the resistance characteristics of the crystal **17** from a positive to a negative region resulting in an appreciable reduction in the potential drop across the diode **13** such as shown by the waveform $V_{13}$ in Fig. 3. At the same time the potential drop across the resistor **14**, as shown by $V_{14}$, initially decreases and then increases and the current through the diode **13** and the resistor **14** rises to the higher of two values whereby the trigger assumes an "on" status.

The trigger will remain in an "on" position until a positive pulse is applied from the pulse source **15** to the junction of the resistor **14** and the diode **13** thereby causing the trigger to shift to the other stable position, the "off" position. When the positive pulse is applied to the circuit, the potential across the resistor **14** will initially increase and then decrease, while the voltage drop across the diode **13** will decrease a slight amount and then increase such that when the trigger assumes its "off" position the voltage drops across the resistor **14** and the diode **13** will be respectively at the lower and higher of two values such as shown in Fig. 3. The trigger will remain in the "off" position until a negative pulse is once again applied to the circuit.



The physical aspects of the germanium or silicon crystal **17** traversal from the positive and negative resistance region and back again are not fully understood. It is believed sufficient to state that when the trigger is initially in an "off" position and the voltage across the diode **13** is raised to the peak **21**$a$, the excursion of the crystal in the negative resistance region is regenerative. When the trigger is in an "on" position and the current therethrough is reduced its excursion from a negative back to a positive resistance region is likewise regenerative.

Inasmuch as the pulse source **15** looks into a relatively low impedance in the form of the resistor **14** it is seen that power is required to drive the trigger circuit of Fig. 1. A circuit which may be triggered by pulses substantially reduced in power is shown in Fig. 4 wherein the resistor **14** of Fig. 1 is replaced by the vacuum tube **22**.

In the circuit of Fig. 4 elements similar to elements in the circuit of Fig. 1 bear identical reference characters.

The electron discharge device or tube **22** is connected in series with the diode **13** with the anode of vacuum tube **22** coupled to the whisker **19** while the cathode thereof is directly coupled to the line **12**. The control grid of the electron device **22** is coupled through the resistor **23** to the potentiometer **24** coupled across the lines **12** and **25**. The lines **12** and **25** are connected to a bias power source not shown while, as in Fig. 1, the lines **11** and **12** are coupled to a main power source which is not shown. The wiping arm of the potentiometer **24** is adjusted in order to bias the tube **22** such that it will be conductive for both of the stable positions of the trigger. The control grid of the tube **22** is also coupled through the capacitor **16** to a source **15** of positive and negative pulses.

Now assuming that the trigger is in an "off" position, it is to be noted from Fig. 5 that the resistance of the diode **13** is positive and relatively high, and that the current through the diode **13** and the tube **22** is at the lower of two values. Likewise it is to be noted from Fig. 6 that the voltage drop across the diode **13** is higher of two values and that the voltage drop across the tube **22** is at the lower of two values. Also the quiescent operating point when the trigger is "off" is that as indicated in Fig. 7.

The trigger circuit of Fig. 4 is switched from an "off" to an "on" position when a positive pulse is fed from the source **15** to the control grid of the tube **22** causing the tube to be rendered more conductive. As a result of tube **22** being made more conductive, the current flow through the diode **13** and the tube **22** will increase causing an initial increase in the potential drop $V_{13}$ across the diode **13** as shown by the voltage peak **30** in the waveforms of Fig. 6 and decrease in the potential drop $V_{22}$ across the tube **22** as shown by the voltage drop **31** in the waveforms of Fig. 6. After the voltage drop across the diode **13** has reached its peak value, the diode **13** will shift rapidly from a positive to a negative resistance characteristic causing the voltage drop across the diode to decrease to the value shown in Fig. 6. Likewise after the diode **13** shifts from a positive to a negative resistance characteristic, the potential drop across the tube **22** shall increase to the value shown in Fig. 6. It is to be noted from Fig. 7 that since the diode **13** is now operating in the negative resistance region that the load resistance for the tube 22 has been lowered causing the shift in the load line from load line 26 to load line 27.

Thus when the trigger assumes its "on" position, it is to be noted from Fig. 6 that the potential drop $V_{22}$ across the tube 22 is at the higher of two values; that the voltage drop $V_{13}$ across the diode 13 is at the lower of two values; that from Fig. 5 the current is at the higher of two values; and that from Fig. 7 the grid bias of the tube 22 remains unchanged.

The trigger will remain in an "on" position until a negative pulse is applied to the grid of the tube 22 from the source of pulses 15. Upon such happening the current flow through the diode 13 and the tube 22 will greatly diminish, as represented by the intersection of the load line 27 with the horizontal axis in Fig. 7, and the voltage drop $V_{22}$ across the tube will approximate the applied potential as shown by the horizontal axis in Fig. 7, and the voltage drop $V_{22}$ across the tube will approximate the applied potential as shown by the peak voltage 28 in the waveform $V_{22}$ of Fig. 6 while the potential drop across the crystal diode 13 will approach zero. In shifting from the "on" to the "off" position the resistance characteristic of the diode shall change from a negative to a positive characteristic resulting in the resistance of the diode being increased, causing a change in the slope of the load line from line 27 to line 29 (Fig. 7). In the "off" position the potential drop across the tube 22 is decreased to the lower of two values, while the potential drop across the diode will be increased to the higher of two values. The difference in slope between the load lines 26 and 29 may be traced to the fact that the resistance of the tube 22 is materially lowered when the tube is made more conductive at the time the trigger is shifting from an "off" to an "on" position.

While there have been shown and described and pointed out the fundamental novel features of the invention as applied to a preferred embodiment, it will be understood that various omissions and substitutions and changes in the form and details of the device illustrated and in its operation may be made by those skilled in the art without departing from the spirit of the invention. It is the intention, therefore, to be limited only as indicated by the scope of the following claims.

What I claim is:

1. A trigger circuit having two conditions of stable equilibrium comprising a block of semiconductor material having positive and negative impedance characteristics, a metallic base coupled to one side of said block, a point contact means coupled to the side parallel to said one side of said block, current limiting means serially coupled to said point contact means, said material exhibiting a positive impedance characteristic while in one of said conditions and exhibiting a negative impedance characteristic while in the other of said conditions, and pulsing means coupled to the junction of said limiting means and said point means for changing the impedance characteristics of said material whereby said circuit shifts from one condition to the other condition of equilibrium.

2. A trigger circuit having two stable positions of equilibrium comprising a variable impedance including a semi-conductor element, an electron discharge device serially coupled to said impedance, said impedance exhibiting a positive resistance characteristic in one of said positions and a negatve resistance characteristic in the other of said positions, means including a source of pulses coupled to said device for inducing a change in said characteristics whereby said circuit shifts from one position to the other.

3. A trigger circuit capable of being reversed from one state of equilibrium to the other comprising a crystal diode, an electron discharge device serially coupled to said diode, said diode having a positive resistance characteristic in one of said states and a negative resistance characteristic in the other of said states, means including a source of pulses coupled to said device for inducing a change in said characteristics whereby said circuit shifts from one state to the other.

4. A trigger circuit having two stable operating positions comprising a two terminal variable impedance device including a semi-conductor element, said device having a positive resistance characteristic in one of said positions and a negative resistance characteristic in the other of said positions, a low conducting electron discharge device serially coupled to said impedance device, means including a source of pulses coupled to said device for causing a change in said characteristics whereby said circuit shifts from one position to the other.

5. A trigger circuit operable to two sustained conditions of equilibrium comprising a block of semi-conductor material having positive and negative impedance characteristics, a metallic base coupled to one side of said block, point contact means coupled to the opposite side of said block, a low conducting electron discharge device connected to said contact means, and means including a source of pulses coupled to said device for inducing a change in said characteristics whereby said circuit shifts from one condition to the other.

6. A trigger circuit operable to two sustained conditions of equilibrium comprising a two-terminal variable impedance device, said device having positive and negative impedance characteristics, biased electron discharge means serially coupled to said device, and means including pulse means coupled to said electron means for causing a change in said characteristics whereby said circuit shifts from one of said conditions to the other.

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**References Cited** in the file of this patent

UNITED STATES PATENTS

| Number | Name | Date |
|---|---|---|
| 2,531,076 | Moore | Nov. 21, 1950 |
| 2,565,497 | Harling | Aug. 28, 1951 |

OTHER REFERENCES

Article—"A Transistor Trigger Circuit" by Reich and Ungvary, from the August 1949 issue of Review of Scientific Instruments; vol. 20, No. 8, pages 586–588.

Article—"Some Novel Circuits . . . Amplifier" by Webster et al. from March 1949, RCA Review, vol. 10, No. 1, pages 5–16 inclusive.